

## AVIONICS SYSTEMS INTEGRATION TECHNOLOGY

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Introduction

A very dramatic and continuing explosion in digital electronics technology has been taking place in the last decade. The prudent and timely application of this technology will provide Army aviation the capability to prevail against a numerically superior enemy threat. The Army Avionics Research and Development Activity (AVRADA) at Fort Monmouth, and NASA at Langley Research Center have been exploiting this "high technology" explosion in the development and application of avionics systems integration technology for new and future aviation systems.

This paper will discuss a few selected AVRADA avionics integration technology base efforts and the Avionics Integration Research Laboratory (AIRLAB) that NASA has established at Langley Research Center, for research into the integration and validation of avionics systems, and evaluation of advanced technology in a total systems context.

Avionics System Integration

Over the past decade the integration of avionics systems has developed to the point where it can be considered a technology in and of itself. Data processors, data communication links, and software are the key elements of system integration technology. The manner in which these elements are partitioned and configured is referred to as system architecture. Considerable benefits in performance, cost, weight, space, power, logistics and maintenance, flexibility, and growth potential are offered by highly integrated systems. However, to achieve these benefits and obtain the required levels of system availability and reliability, fault tolerance must be an essential and critical element in system architecture design. A fault-tolerant system architecture can provide high levels of coverage of failures and the inherent capability to reconfigure the system after a failure to thereby maintain system functionality.

Thus the system can continue to function, possibly at degraded but acceptable levels of performance, for extended periods of time. As modules fail and repeated reconfigurations occur, the avionic system will degrade gracefully. However, the aircraft will be available to fly numerous missions, with acceptable levels of performance, before maintenance actions are necessary. In addition, the high level of fault isolation capability inherent in a fault-tolerant architecture will allow isolation of the fault to the module level. Thus, maintainability is enhanced because the failure is accurately diagnosed on-line to the module level, which can subsequently be replaced by a straight forward maintenance procedure.

### Integrated Avionics Control System

In the Mid 1970's, in an effort to solve the acute problems of available cockpit panel space and crew workload in Army Helicopters, AVRADA initiated the development of the Integrated Avionics Control System (IACS). IACS, employing embedded microprocessors, digital multiplex data buses, and highly integrated multifunction cockpit control/display units, embodied the leading edge of the state of the art for the mid to late 1970's time frame. The IACS block diagram and controlled avionics are shown in Figures 1 and 2 respectively. The pilot can control all communications, navigation, and identification (CNI) equipment from a single control panel. Two central control units serve as bus interface units for non-bus compatible remotely located CNI equipments and all digital data between the cockpit and remote avionics bay is via MIL-STD-1553 data bus. Fault-tolerance is accomplished via redundancy and cross-strapping techniques.

IACS was very successful in meeting its program objectives of reducing cockpit panel space requirements and reducing pilot workload. A single multi-function IACS primary control panel utilizing approximately 40 square inches of cockpit panel space replaced 240 square inches of separate functionally dedicated cockpit mounted avionics controls and equipments. Regarding workload, the United States Army Aviation Test Board concluded from operational testing at Fort Rucker, AL that "The Integrated Avionics Control System provides the pilot a cockpit management system that reduces pilot workload. All avionics can now be controlled from one central location. By spending less time in the cockpit programming different radios, the pilot is able to perform the demanding tasks associated with NOE flight more safely and efficiently."<sup>3</sup>

The importance of the IACS program was that it successfully demonstrated the benefits of integrated avionics systems to the Army and provide the basis for further avionics system development efforts. IACS provided the needed impetus to develop avionics equipments capable of MIL-STD-1553 operation and provided the basic principals by which a totally digital avionics system architecture could be conceived. Derivatives of the IACS are currently used on the Coast Guard HU-25A, HC-130H, HH-65A, the Air Force A-10, KC-135, the U.S. Navy H-3, Army SEMA, and versions of the CH-47, AH-64, and UH-60.

## Army Digital Avionics System

Based upon the technical success of IACS, and continued advancement in digital technology, it became apparent that integration of the total avionics system was possible. The next step was to expand the core IACS CNI control function to include additional cockpit management functions, such as flight displays, engine displays, caution/warning advisory subsystems, electrical power, aircraft secondary systems, preflight checklists and emergency procedures. In the late 1970's the Army Digital Avionics Program (ADAS) was initiated to serve as the mechanism for this expansion and to become the cornerstone of AVRADA's technology base for integrated systems architecture and cockpit integration concepts. The subsystems integrated into ADAS are shown in Table 1 below.

AC ELECTRICAL	ENGINE/XMSN CHIP DETECTOR
DC ELECTRICAL	ENGINE OVERSPEED PROTECTION
AFCS CAUTION	ENGINE SPEED TRIM
AIR DATA	ENGINE START AND IGNITION
ATTITUDE HEADING SYSTEM	FIRE DETECTION
ATTITUDE INDICATING	FUEL LO LEVEL WARNING
AUDIO WARNING	FUEL PRIME BOOST
AUXILIARY POWER UNIT	FUEL QUANTITY
COMMAND INSTRUMENT	GUST LOCK WARNING
ROTOR BLADE DE-ICING	HEATING & VENTILATING
ENGINE INSTRUMENTS	HYDRAULICS SYSTEM
ENGINE WARNING	SEARCH LIGHT
ENGINE ANTI-ICE	TAIL ROTOR WARNING
LANDING LIGHT	TAILWHEEL LOCK
ANTI-COLLISION LIGHT	TRANSMISSION INSTRUMENTS
CABIN DOME LIGHTS	TRANSMISSION OIL WARNING
COCKPIT FLOOD LIGHTS	WINDSHIELD ANTI-ICE
COCKPIT UTILITY LIGHTS	WINDSHIELD WIPER
FORMATION LIGHTS	DRAG BEAM SWITCH
POSITION LIGHTS	CYCLIC AND COLLECTIVE SWITCHES
CONSOLE LIGHTS	VHF/FM NO. 1 (IACS)
INSTRUMENT PANEL LIGHTS	VHF/FM NO. 2 (IACS)
NNAPS	UHF/AM (IACS)
PARKING BRAKE	VHF/AM (IACS)
PITOT HEATER	IFF (IACS)
RADAR ALTIMETER	DOPPLER NAVIGATION (IACS)
RATE OF TURN	VOR/ILS (IACS)
LANDING SYSTEM	LF/ADF (IACS)
PREFLIGHT CHECKLIST	EMERGENCY PROCEDURES

TABLE 1 - SUB-SYSTEMS INTEGRATED BY ADAS

ADAS was designed to integrate the total cockpit management functions of the UH-60A Black Hawk aircraft. A system block diagram of ADAS is shown in Figure 3, and the ADAS UH-60 cockpit is shown in Figure 4. It should be noted that IACS has been incorporated into ADAS as a complete CNI subsystem that operates under dynamic bus control allocation protocol. The crew interface for the non IACS functions are four multi-function displays and two keyboard terminal units. Line select keys located around the periphery of the displays allow menu and page selection by the crew. Eight remote terminal units provide the interface to hundreds of aircraft sensors, transducers, and electrical signals. Generation of alpha-numerics and vector graphics are accomplished in two programmable signal generators. The processing elements consist of two SDP-175 16 bit microprocessors. Programming is in assembly language; however, concepts of structured software with partitioned software modules have been applied. Data communication between elements is via dual redundant MIL-STD-1553 multiplex data buses.

The ADAS system has been installed on the AVRADA UH-60A System Testbed for Avionics Research (STAR) aircraft. The flexibility and growth potential provided by ADAS is well suited for use in AVRADA's flying laboratory for testing of new architectures, avionics equipments, and concepts. The STAR in its role as a research aircraft is a vital tool in the Army's pursuit of cockpit automation and advanced avionics technologies. Concepts and equipments developed in ADAS have greatly influenced the design of and are being employed in AHIP, the first fielded digitally integrated aircraft, and the OV-1B Mohawk Block Improvement Program.

### Digital Map Generator

Another significant AVRADA avionics integration effort is the Night Navigation and Pilotage System (NNAPS) for which the first practical airborne digital map generator was developed. The NNAPS is a special purpose, very high speed digital processing system consisting of flight and tactical symbology generation, topographic map display generation, and an autonomous terrain-aided navigation system. A wide variety of operator-selectable symbology formats are used to display pilotage information which is superimposed on a FLIR or TV image (Figure 5), and navigational information which is superimposed on a map image (Figure 6).

The symbology was developed at AVRADA in the flight simulator and intensively flight tested in the STAR aircraft. The map image is generated from a digitized topographic data base consisting of terrain elevations and planimetric features such as vegetation, hydrography, transportation networks, structures, etc.

This same topographic data is also accessed by a terrain-aided navigation processor which uses a Kalman filter to estimate the vehicle's position errors. When these estimates are coupled with the unaided Doppler navigation system, positional accuracies of 50 to 100 meters can be achieved.



The capability to use digitized topographic data for both map generation and other functions such as terrain-aided navigation and threat management is a major advantage of a digital mapping system over alternative map display systems which are paper map based such as projected map displays, remote film strip map readers, etc.

The first flyable digital map hardware was developed at AVRADA and flight tested in the STAR in early 1983. It consisted of storing precomputed map images on magnetic tape for recall to a digital display memory and subsequent video readout to a standard television monitor located on the instrument panel. Stationary, black & white TV map images could be displayed at several fixed orientations and scale factors. For flight demonstrations conducted at Carlisle, PA, north up 6x6km and 12x12km map formats were used exclusively. Navigation symbology which included a moving aircraft symbol driven by an unaided Doppler output was generated externally for registration and video inseting on the map image. A course line was also provided by the symbol generator for inseting on the map between check points. This system achieved high acceptance by Army test pilots during many NOE flights at Carlisle.

Concurrent with AVRADA's in-house development of this rudimentary system, a contract was awarded to the Harris Corporation, Melbourne, FL, for the design and fabrication of a Digital Map Generator (DMG) whose principal function would be the real-time generation of a topographical map portraying both terrain elevation and planimetric information in a standard closed-circuit color television format. This highly interactive, moving-map system has been delivered and installed in AVRADA's flight simulator for test and evaluation. A magnetic four-track tape unit is used as the bulk storage device for the digitized topographic data base. Terrain elevation and planimetric data are stored in a compressed format on the first two serial tape tracks to cover a 100x100km geographic area. The remaining two tracks are available for field intelligence and mission-specific data which can be added during mission planning.

During operation, the desired map position and orientation angle are transmitted to the DMG, which can process these inputs at a rate of 60 Hz. The appropriate blocks of data are read from tape into an intermediate buffering memory from which special high-speed hardware reconstructs this data at the requested display scale into a buffering scene memory.

Readout to the video display at the desired map orientation angle is accomplished with special purpose hardware processors which generate the selected contour field and execute the terrain-shading algorithms. If the aircraft position is input as the commanded map position, the map will translate and rotate smoothly in an aircraft-centered, moving-map mode with no time lags or display degradation. The maps can be displayed on any standard color television monitor.

A programmable color mixing table located in the DMG output circuitry is loaded at initialization and used to assign desired

colors to specific planimetric features such as green for vegetation, blue for hydrography, etc. A programmable symbol table is also loaded at initialization and used to assign 8x8 matrix shapes to each of the 128 point features that the DMG can process. The point symbols are pinned at their specific map coordinates but always displayed in a screen up orientation for readability.

Input/Output communication with the DMG is accomplished through a 16 bit parallel interface under external computer control. At AVRADA's flight simulator, this is done via a DR-11W interface to a DEC VAX-11/780 computer. This design offers maximum flexibility in the development of map control software which can be tailored for the user's specific applications.

Operator interaction with the DMG is accomplished with a Control Display Unit (CDU) which is also interfaced with the external computer. The CDU presents the pilot with a list of control options via a computer generated menu and transmits selected options back to the external software which sends the appropriate commands to the DMG.

There are several types of DMG interface functions which permit the operator to actively configure the map video to any desired format:

For example, The DMG may be commanded to any map coordinate stored in the compressed data base on tape. This map point may be selected to coincide with either screen center or 1/4 of the way up from bottom which affords more look ahead distance if the aircraft position is used to drive the map in a moving mode.

Map orientation angle may be driven by the aircraft heading, in which case the map will rotate in a heading up mode, or by the aircraft track or some other fixed angle, such as north, resulting in map translations only.

Map display coverage per screen area may be selected by the operator as well. There are four display scales available for Army applications - 3x3km, 6x6km, 12x12km, and 24x24km. The 6km and 12km scales appear to be the most useful during actual flight, however the 3km scale may prove useful at lower velocities and the 24km scale is desirable during mission planning use (Figures 7, 8, 9,).

Two types of shading are available for operator selection - elevation shading and slope shading. In the elevation shading mode (Figure 10), the map is shaded as a function of terrain elevation bands with the darker shades normally assigned for the higher elevations. There are eight elevation bands whose relative width and absolute vertical positioning may be chosen by the operator for optimum information content. This mode can also incorporate the aircraft altitude into the shade assignment to provide the capability for terrain avoidance.

In the slope shading mode (Figure 11), the map is shaded with sixteen levels of intensity as a function of terrain slopes. The result is a more realistic visual presentation analogous to the relief shading associated with paper maps.

One of the most useful attributes of the DMG is the flexibility afforded the operator in selecting exactly what planimetric features appear on the display. Any combination of topographical and/or tactical feature subsets may be chosen and only those features which are selected will be displayed.

Another very critical function which is accomplished with the DR-11W interface is data base interrogation. The external computer may request a block of reconstructed elevation and planimetric data from the DMG. This data is then available for manipulation by external software which executes the terrain-aided navigation and threat management computations. As stated earlier, this is a major advantage of a digital mapping system and the importance of such a capability cannot be overestimated.

Digital Map Technology developed by AVRADA has been effectively demonstrated in the Army Advanced Rotorcraft Technology Integration (ARTI) and the Air Force Advanced Fighter Technology Integration Programs. Digital Map Systems will be employed in LHX and other future rotorcraft systems.

#### Fault Tolerant Systems Research

AVRADA recognized the need and provided for fault-tolerance in the IACS and ADAS architectures through redundancy. Future aircraft will employ digital electronic systems to perform flight critical functions which must be ultra-reliable as failure could result in the loss of the aircraft. The design and validation of ultra reliable systems present special problems not found in the design and validation of conventional systems and new techniques and methods are needed to evaluate their performance and reliability. No longer will exhaustive testing be practical because of the excessive time required and cost incurred to build confidence that the reliability requirements can be met. Therefore, attention must be given to defining techniques and methodologies for ensuring that advanced system designs meet performance and reliability requirements without having to rely on exhaustive testing. Research is being conducted at the NASA Langley Research Center to provide an effective validation methodology, techniques for conducting comparative analyses of advanced system concepts, and guidelines for designing fault-tolerant systems that will be easier to validate.

As shown in figure 12, the work at the Langley Research Center includes development of analytical models for reliability estimation, economic assessment, and software error prediction; design proof techniques; emulation capabilities; and experimental procedures leading to the definition of a generic validation methodology.

These techniques and methods are verified and refined by applying them to specimens of fault-tolerant computers and systems using the capabilities of the Avionics Integration Research Laboratory (AIRLAB) facility. Candidate tools and techniques become a part of a proposed validation methodology that is applied to advanced system concepts or proof-of-concept hardware models in AIRLAB as illustrated in figure 13. Experiments provide information on the effectiveness of the proposed methodology and the candidate tools and techniques, as well as data on the performance and reliability characteristics of the system test specimen.

AIRLAB is a national facility that provides many opportunities for cooperative activities between NASA, industry, academia, and other government agencies by researchers who are interested in the design and validation of highly reliable fault-tolerant systems. AIRLAB became operational at the Langley Research Center in 1983 to support research that will become the basis for developing design and validation methodologies. The basic attributes and capabilities of the physical laboratory continue to evolve as the requirements for research in the area of fault-tolerant systems progress.

AIRLAB is a 7600 square foot, environmentally controlled laboratory partitioned into three distinct areas as shown in figure 14. The largest area contains eight research work stations and a central-control station. The next largest area is the computer room containing nine VAX 11/750's and a VAX 11/780. Each VAX 11/750 has 2 megabytes of memory and 56 megabytes of local disk storage. The VAX 11/780 has 4 megabytes of memory and 160 megabytes of local disk storage. All 10 of the VAX minicomputers are interconnected with a 256 kilobaud serial digital communication network with DECNET communications software. The third area contains a horizontally microprogrammable Nanodata QM-1 computer that hosts a unique diagnostic emulation algorithm for use in emulating digital devices at the lowest logical level. Each research station is configured with an extensive set of peripherals as well as digital and analog input/output devices. A block diagram for a typical research station is shown in figure 15. Four of the research stations also have MEGATEK 3-D graphic systems with high resolution color monitors. AIRLAB provides a capability for conducting experiments without the necessity of each experimenter having to learn the details of the facility hardware and software. A unique software feature of AIRLAB is the Data Management System (DMS) which is the prime interface for experimenters to access information about the laboratories capabilities. A major goal of the DMS is to allow users to be as productive as possible by providing centralized, easy access to AIRLAB capabilities and research results. The DMS collects data about experiments, organizes it, provides easy access to it, and ensures its integrity. The DMS operating environment, accessible from all AIRLAB VAX computers, is largely menu-driven and offers extensive on-line help. Log-on and log-off procedures are used to track the user's activities on the system and captures as much information automatically as possible. An on-line engineering

notebook allows the user to make notes about current work whenever desirable. The user can later search the notes both chronologically and by key words to recall information about the work. Most experimental data collected will initially be kept on-line but will eventually be archived on tape. The DMS provides the capability to facilitate accessing information in archived files using an on-line catalog of all archived files coupled with the ability to browse and search the catalog simply and easily. The DMS also includes a software configuration management system that facilitates the development of user software programs, provides problem reporting and tracking mechanisms, and provides a catalog of all the available software. For those experiments that require access to the VAX operating system, the capability is provided to move easily from the DMS to the operating system and back to the DMS. Other support software currently available is listed below.

- o OPERATING SYSTEM

- VAX/VMS

- VAX/ELN

- o LANGUAGES

- Ada

- FORTRAN

- VAX - 11 ASSEMBLER

- PASCAL

- C

- BASIC

- LISP

- BLISS 32

- o WORD PROCESSING AND REPORTING

- MASS - 11

- DATATRIEVE

- o GRAPHICS

- TEMPLATE

- WAND (MEGATEK)

The design of AIRLAB provides the flexibility to support a variety of research configurations. Figure 16 is an illustration of AIRLAB resources configured for conducting multiple independent experiments. Station 1 is the central control station which is directly connected to the VAX 11/780 and is used for software development and data management. Station 2 is used to demonstrate the diagnostic emulator's capability to emulate an avionics microprocessor at the gate level. Stations 3, 4, 5, and 6 are configured for an experiment that is designed to validate

assumptions made in the design proof of a fault-tolerant system synchronization algorithm. Two of the stations, 7 and 8, are used in an experiment to investigate the occurrence of software errors. Stations 9 and 10 are each dedicated to supporting one of two fault-tolerant computer system test specimens that are used for developing validation experiments to characterize fault-handling responses. Figure 17 is an illustration of AIRLAB resources configured to support integrated systems experiments. The station assignments are arbitrary, and the data distribution network is experimental and defined by the experimenter. Another possible configuration of the research stations, figure 18, would allow the experimenter to investigate new fault-tolerant computer concepts where redundant elements of the system are simulated at each station.

Two fault-tolerant computer systems that are currently installed in AIRLAB are the Software Implemented Fault-Tolerance Computer (SIFT) and the Fault-Tolerant Multiprocessor (FTMP). As the name implies, the SIFT computer shown in Figure 19 isolates faults primarily with voting techniques implemented in software. Upon detection of an error using a software voter the operating system software decides which element of the system is faulty and invokes a reconfiguration task to eliminate the faulty element. The FTMP computer has a very different architecture from SIFT as seen in Figure 20. FTMP initially detects faults in a hardware voter and error detector. The FTMP operating system software also invokes a reconfiguration task to eliminate the faulty elements of the system. Both the SIFT and FTMP computers are available for developing validation experiments and analytical procedures.

#### Joint Army NASA Avionics Program

In 1985 the Army Aviation Systems Command, recognizing the significance of the NASA avionics program at Langley Research Center, and the potential benefits derivable from a cooperative Army NASA avionics effort, authorized the establishment of the AVRADA Joint Research Programs Office (JRPO) at Langley. In 1986, JRPO staffing began and Army research engineers are now performing joint avionics research with NASA research engineers at the Langley Research Center facilities. In AIRLAB, Army engineers are currently participating in two joint research projects in the area of fault tolerant avionics systems. One project is directed toward the development of design guidelines and performance assessment methodologies for advanced fault-tolerant system architectures and the other is investigating methods for estimating software reliability for ultra-reliable systems. In addition to the joint fault-tolerant systems programs in AIRLAB, Army research engineers are performing cooperative research with NASA in developing code for predicting antenna performance on complex rotorcraft structures and in the investigation of advanced cockpit display technology for future rotorcraft.

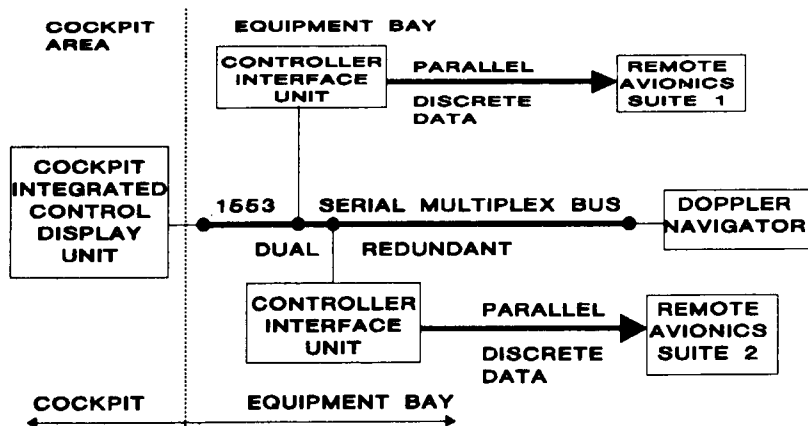
The results of the joint avionics research program at Langley will compliment and provide significant input to the AVRADA technology base and developmental efforts at Fort Monmouth, NJ. During the past decade AVRADA and NASA Langley have been independently exploiting the explosion in digital technology. With the recent establishment of the Army NASA avionics program at Langley it is fully expected that the next decade of the continuing digital electronics technology explosion will be harnessed even more effectively in providing "Hi-Tech" avionics for future Army rotorcraft systems.

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### INTEGRATED AVIONICS CONTROL SYSTEM (IACS)



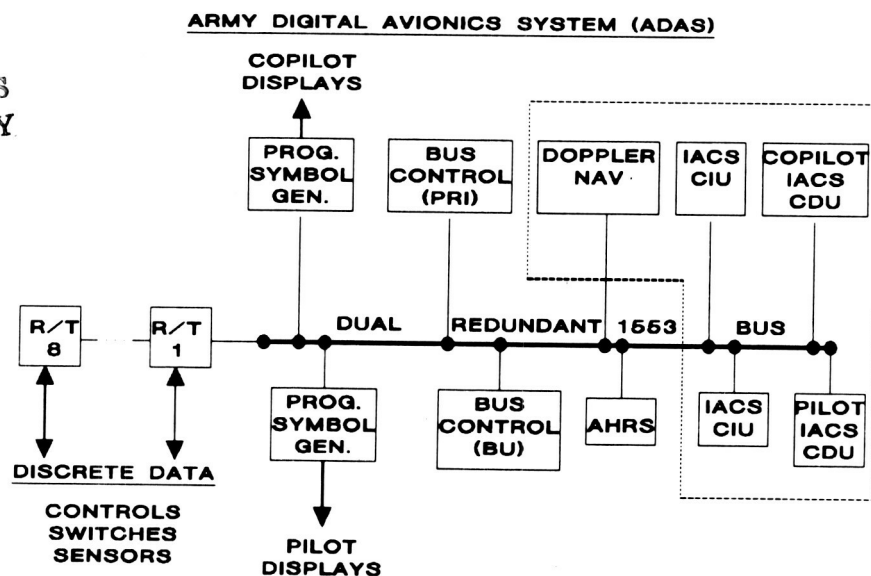
**FIGURE 1**

### IACS CONTROLLED AVIONICS

- VHF-FM RADIO - 2 each
- VHF-AM RADIO
- UHF-AM RADIO
- VOR/ILS
- IFF
- ADF
- DOPPLER NAVIGATOR
- UHF-AM RADIO
- SECURITY DEVICES FOR RADIOS AND IFF

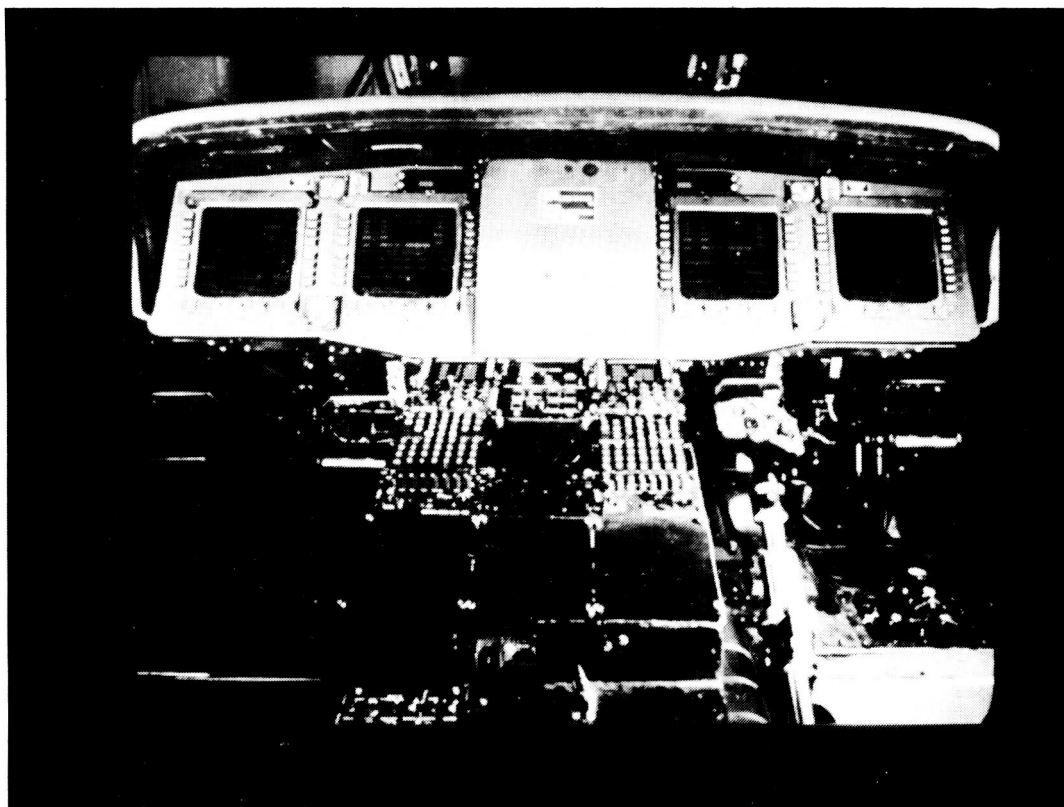
**FIGURE 2**

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**FIGURE 3**

### ADAS UH-60 COCKPIT



**FIGURE 4**

## SUPERIMPOSED PILOTAGE INFORMATION

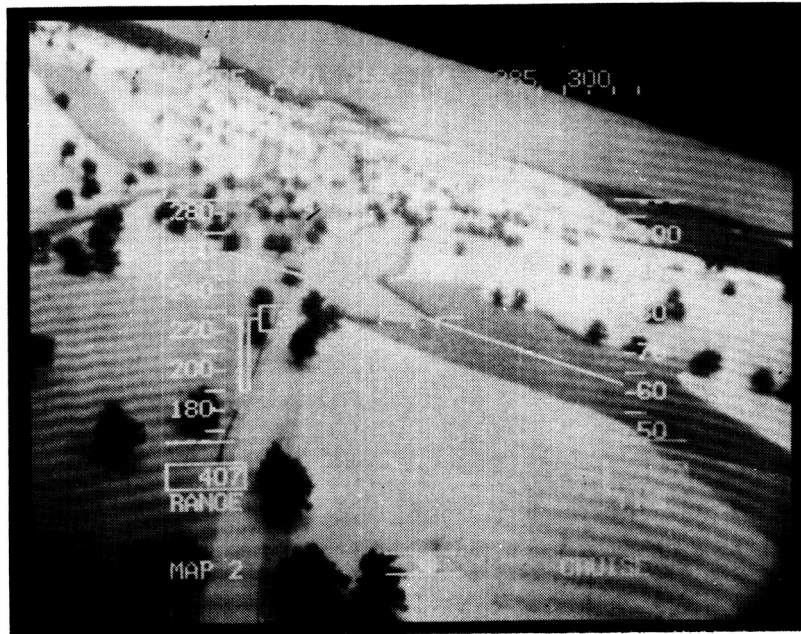


FIGURE 5

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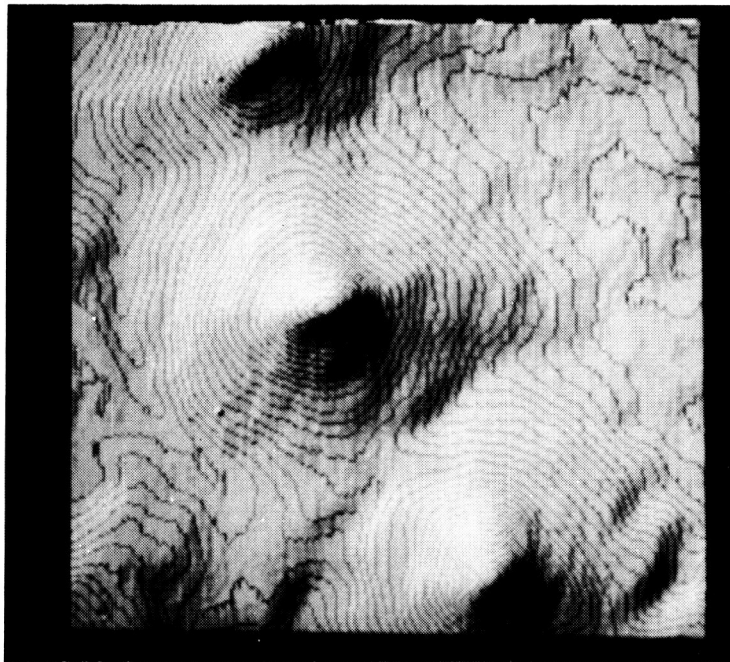
## SUPERIMPOSED NAVIGATION INFORMATION



FIGURE 6

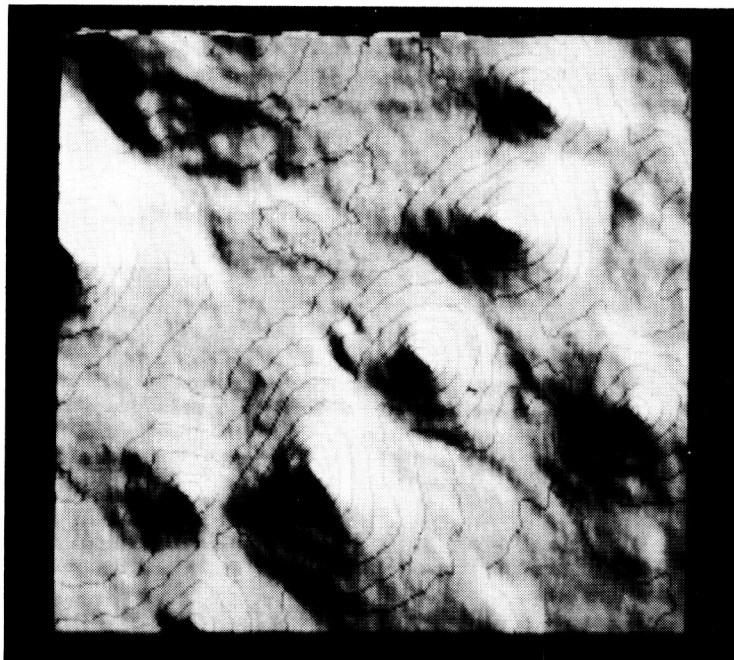
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**3KM X 3KM DIGITAL MAP**



**FIGURE 7**

**6KM X 6KM DIGITAL MAP**



**FIGURE 8**

## 12KM X 12KM DIGITAL MAP

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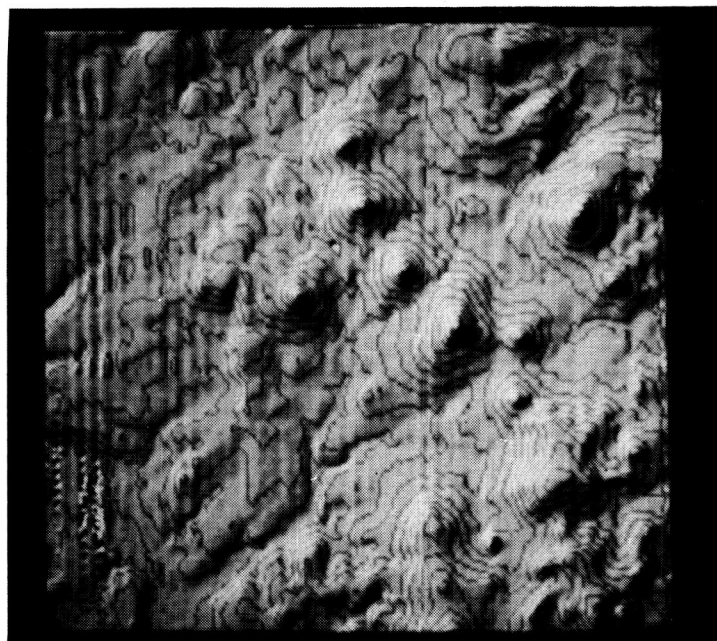


FIGURE 9

## ELEVATION SHADED DIGITAL MAP

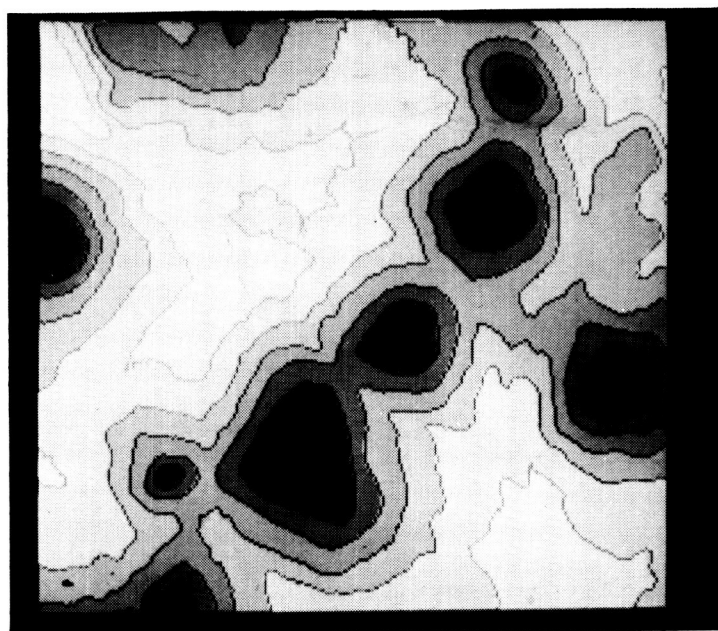


FIGURE 10

## SLOPE SHADED DIGITAL MAP

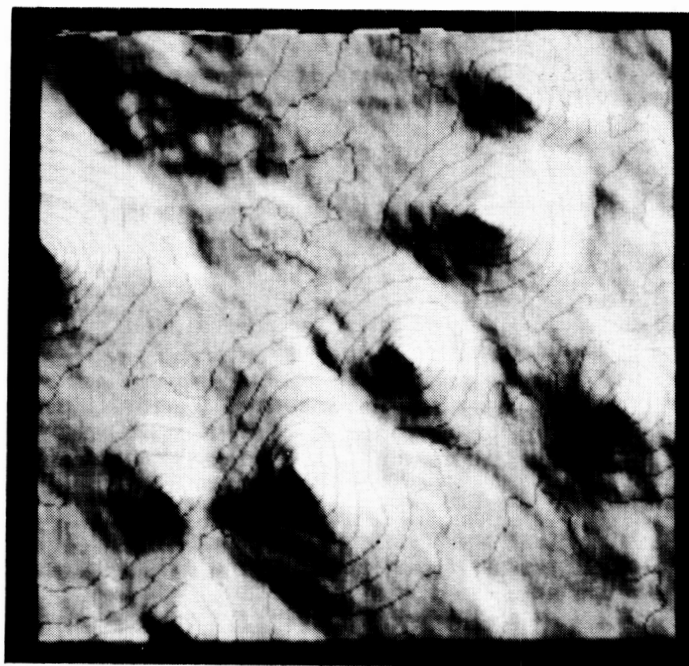


FIGURE 11

## FAULT-TOLERANT VALIDATION METHODOLOGY RESEARCH

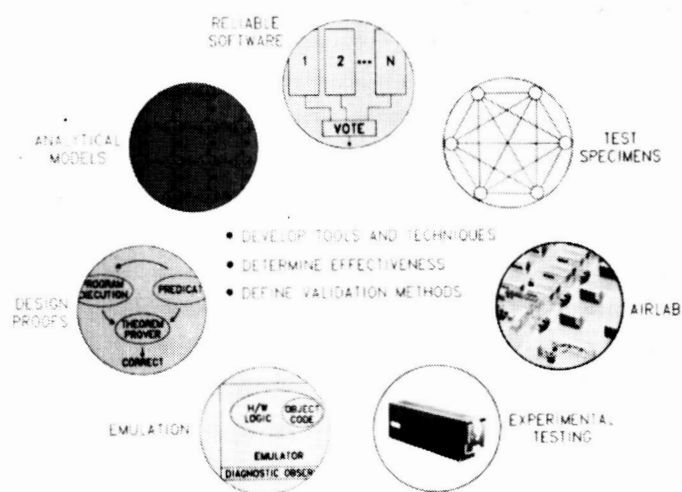


FIGURE 12

# FAULT-TOLERANT SYSTEM RESEARCH

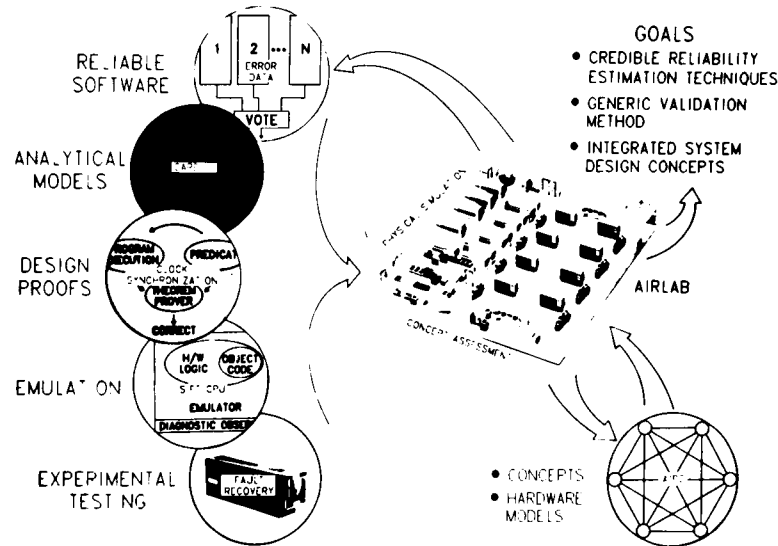


FIGURE 13

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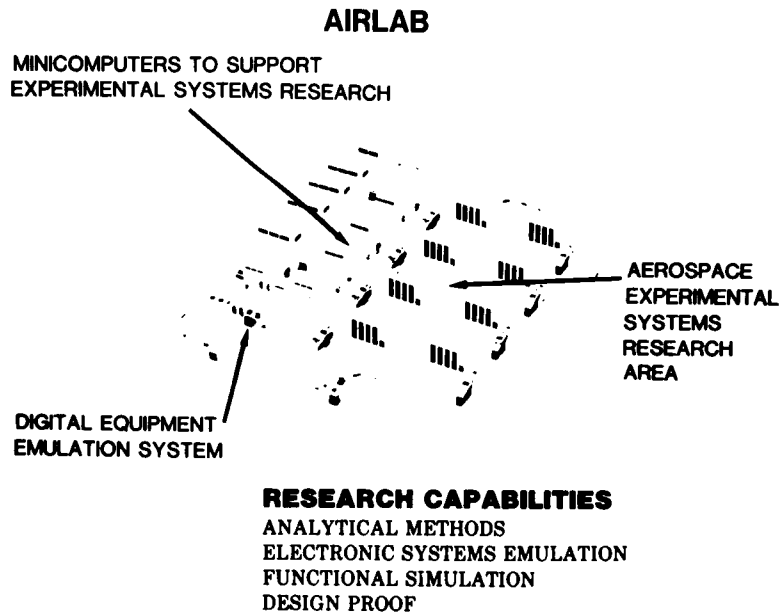


FIGURE 14

# TYPICAL RESEARCH SUPPORT STATION

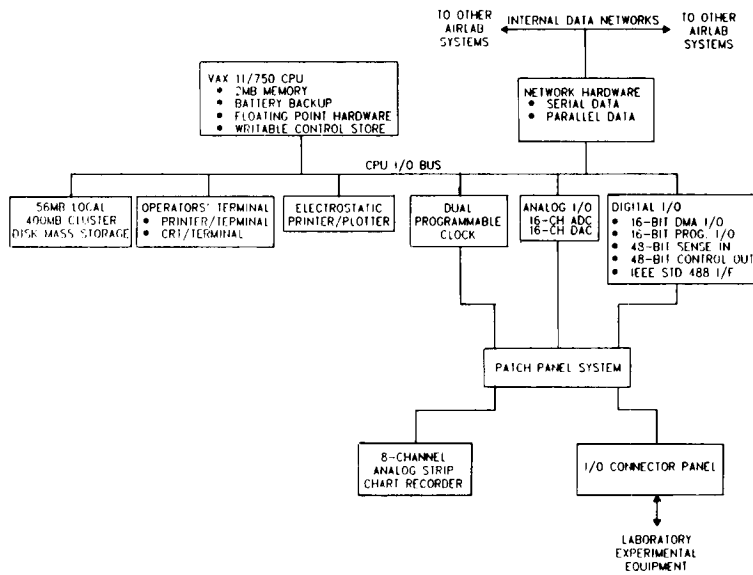


FIGURE 15

## EXPERIMENTAL STATIONS MULTIPLE INDEPENDENT EXPERIMENTS

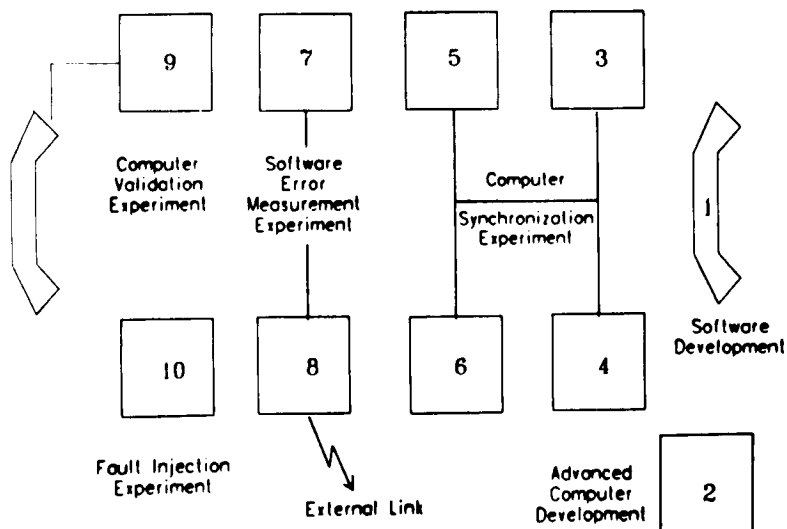
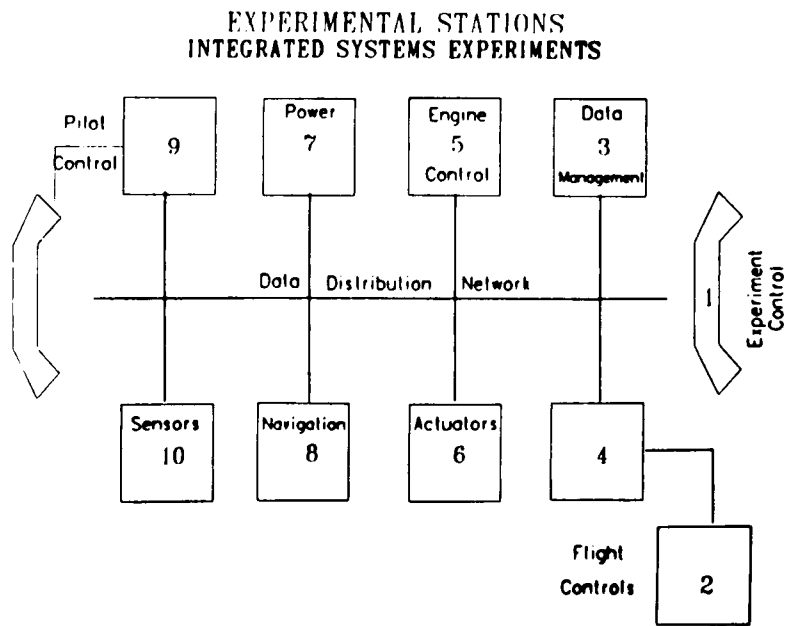


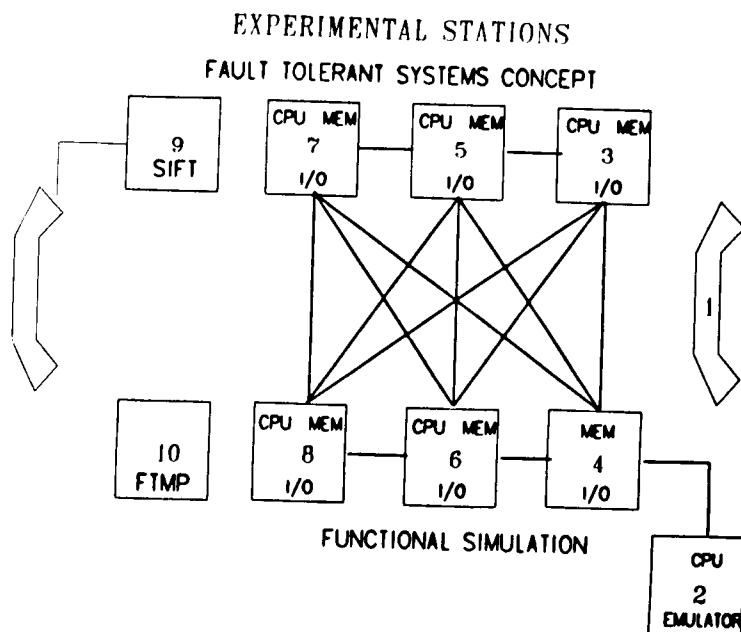
FIGURE 16

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**FIGURE 17**



**FIGURE 18**

# SOFTWARE IMPLEMENTED FAULT-TOLERANCE COMPUTER ENGINEERING MODEL

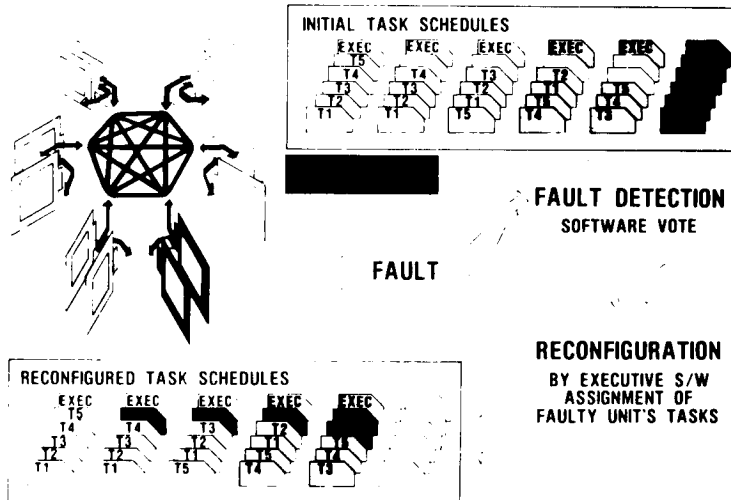


FIGURE 19

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# FAULT TOLERANT MULTIPROCESSOR ENGINEERING MODEL—CSDL&COLLINS

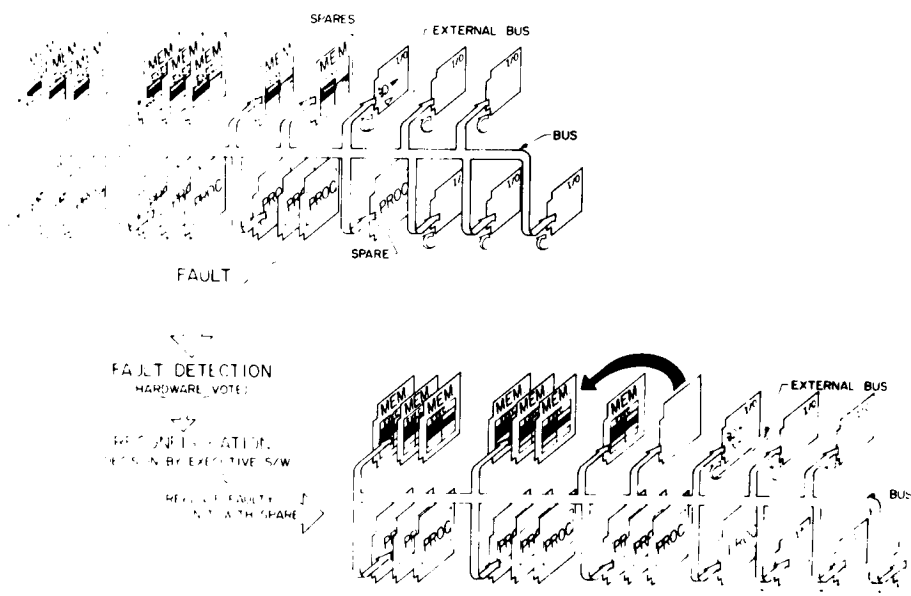


FIGURE 20